Fourth IAEA Technical Meeting on
"Negative Ion Based Neutral Beam Injectors"
Padova, Italy, May 9 – 11, 2005

# Volume Production of $D^-$ Negative Ions in Low-Pressure $D_2$ Plasmas

## - Negative Ion Densities versus Plasma Parameters -

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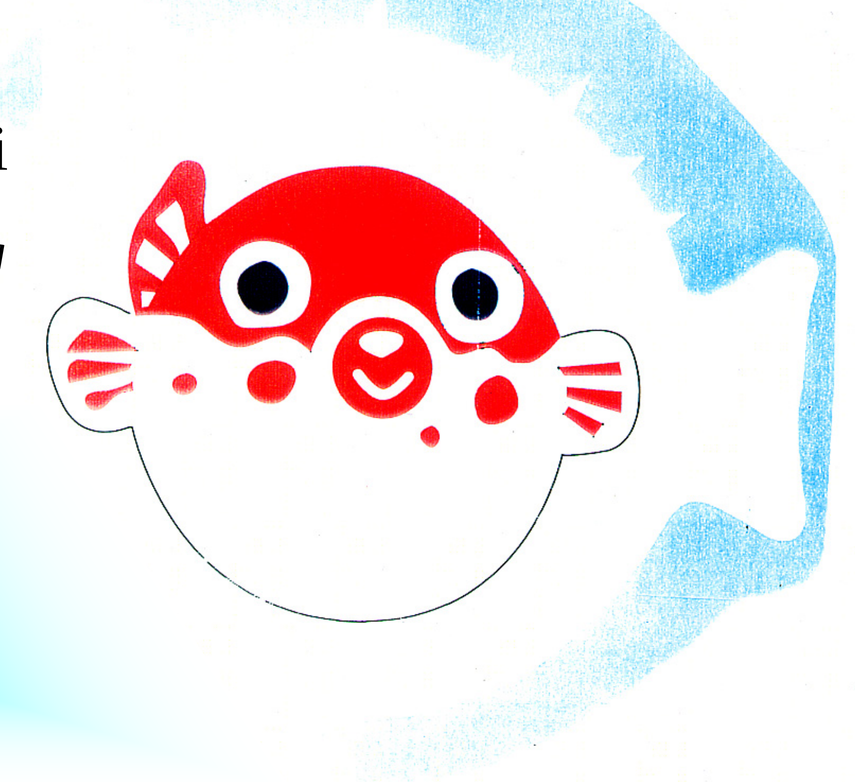


CONTENTS

# Background

Two-step process of $H^-$ volume production

(1) $H_2(v''=0) + e_{fast}$ ($E_{fe}$ > 20-30eV) $\rightarrow H_2^*(v') + e'_{fast}$

$H_2^*(v') \rightarrow H_2(v'') + h\nu$

(2) $H_2(v'' > 5) + e_{slow}$ ($\kappa T_e$ = 1eV) $\rightarrow H^- + H$

Optimization (Enhancement)

Tandem two-chamber system

- optimization of $f(E)$, $n_e$ and $T_e$ $\rightarrow$ magnetic filter/plasma grid

Introduction of cesium

- enhancement of $H^-$ production (surface effect)

# Objectives

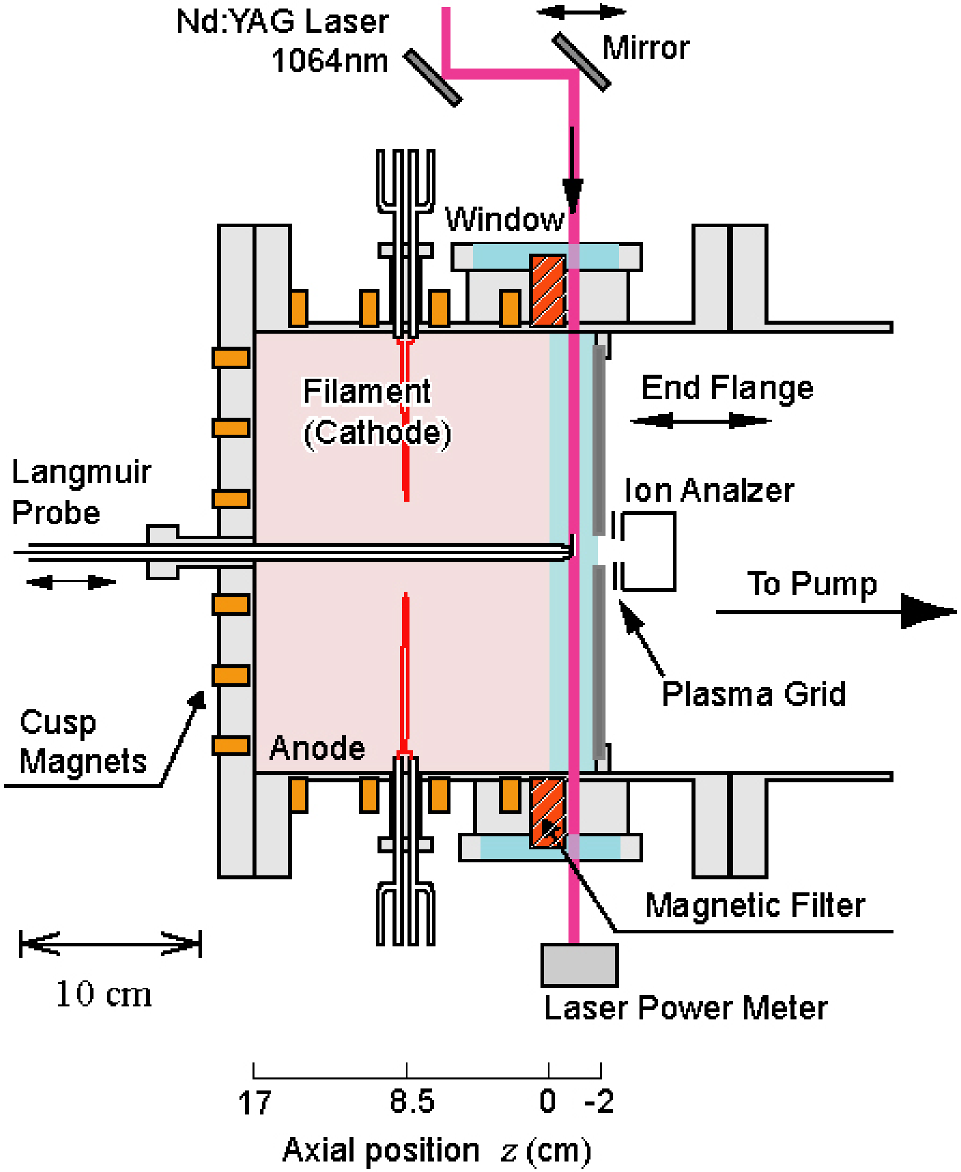
Development of high current $D^-$ ion sources

(1) Production and control of $D_2$ plasmas

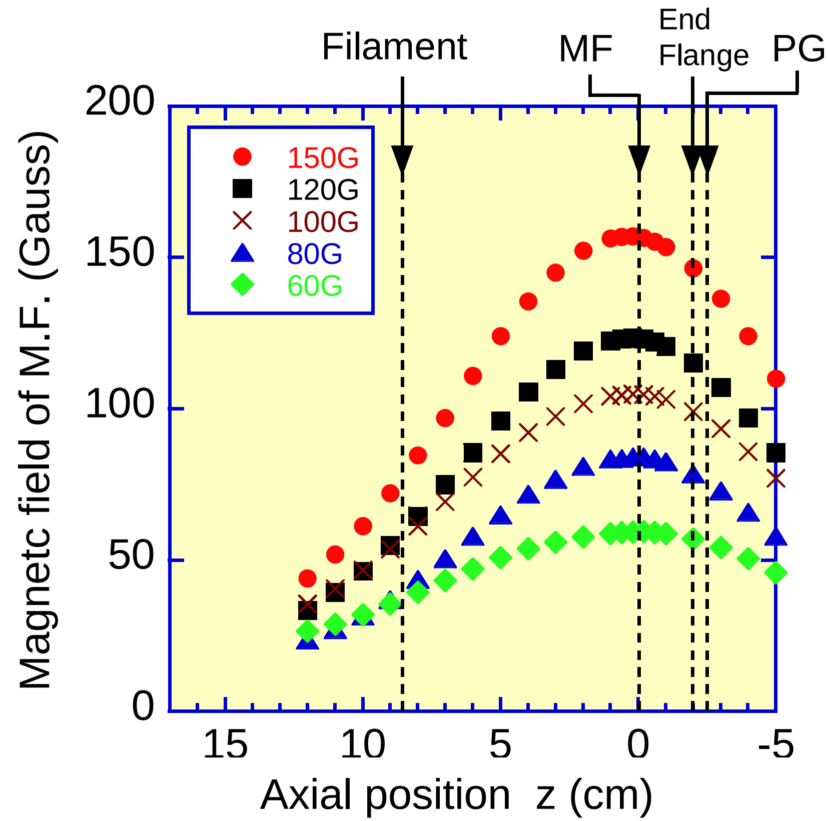
(2) Isotope effect of $H^-$ and $D^-$ production

- measurement of VUV emission
- measurement of $H^-$ and $D^-$ densities
- extraction of $H^-$ and $D^-$ currents

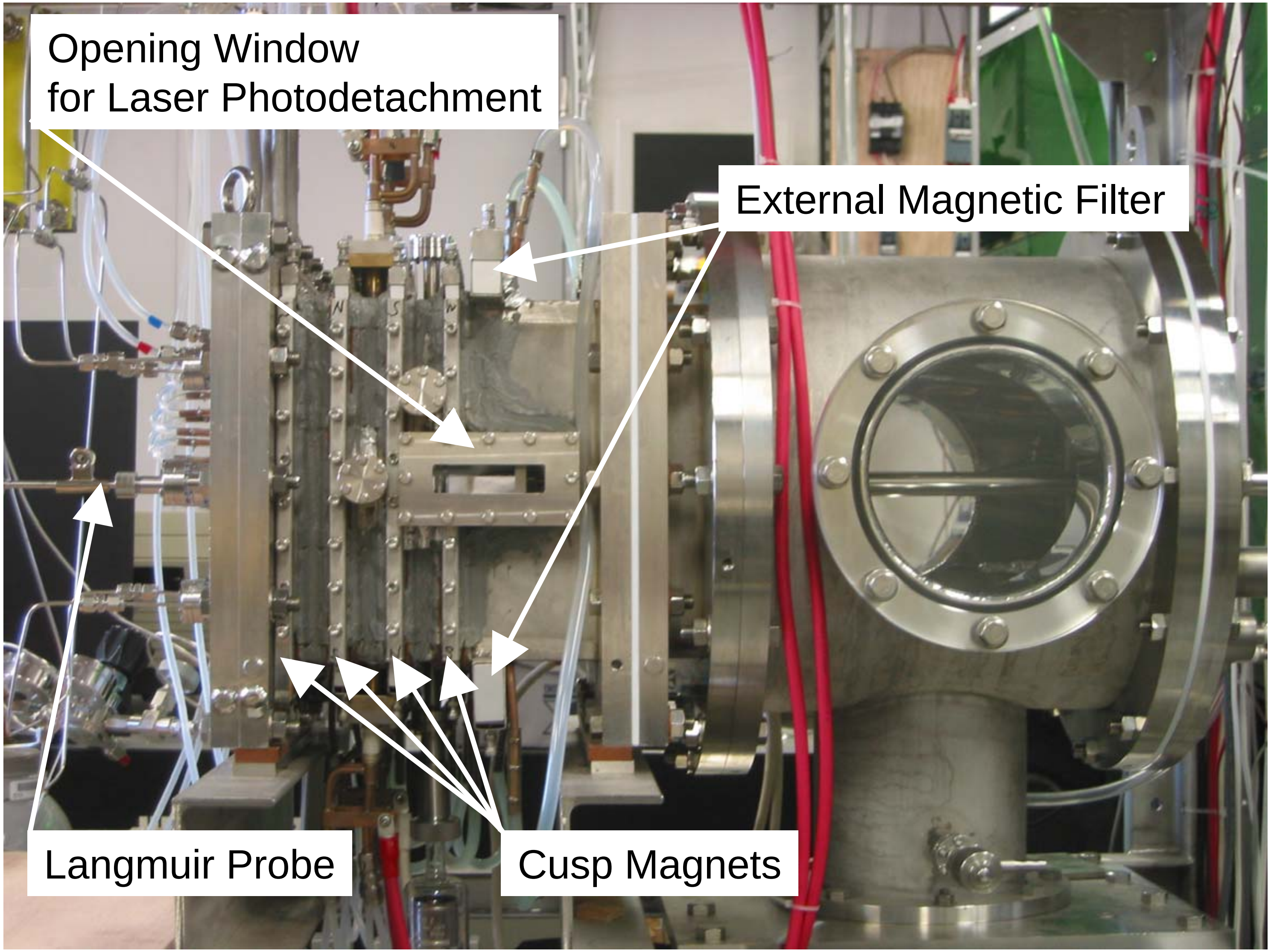
# Experimental Set-up




## Magnetic Filter Fields



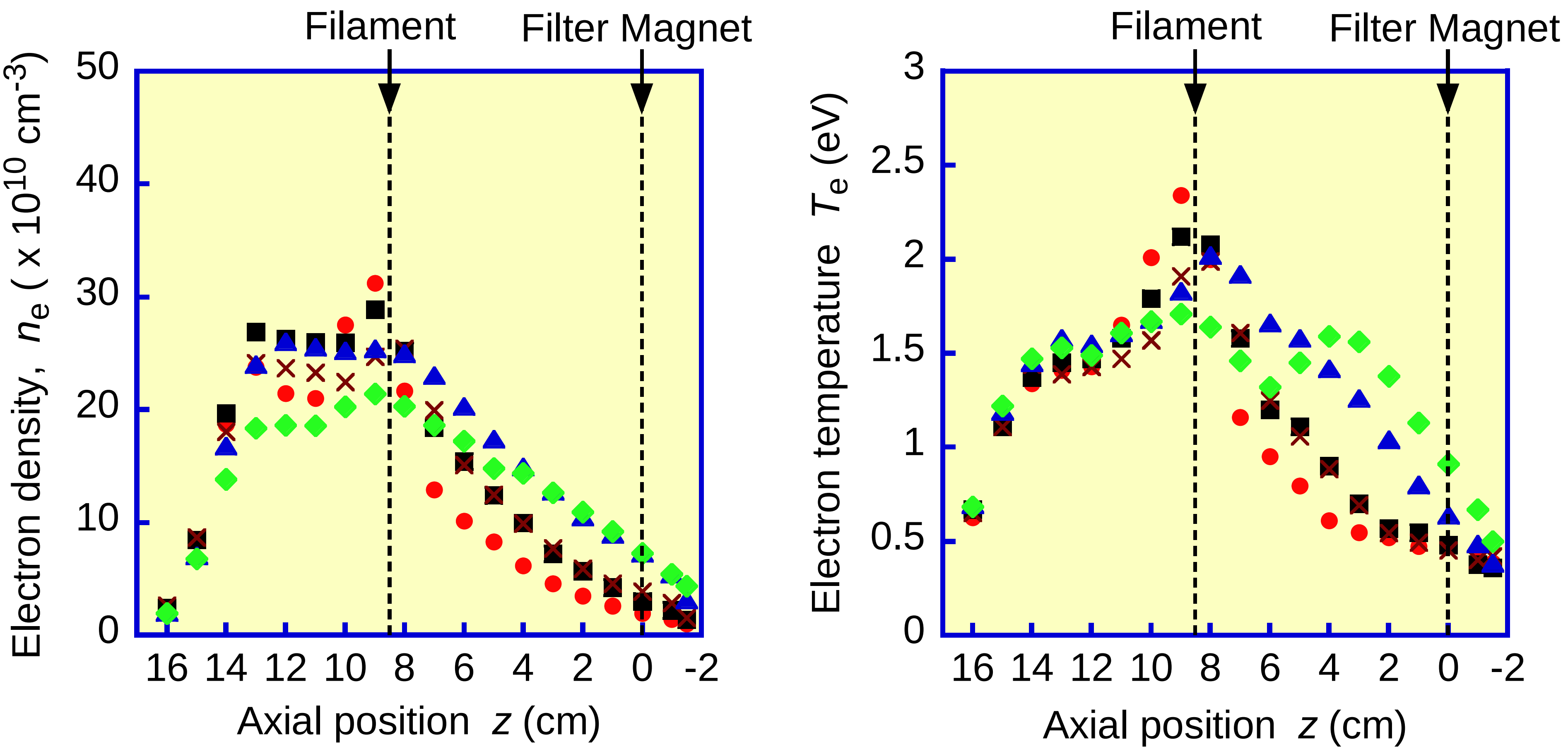
# Experimental Set-up



# Axial distributions of plasma parameters in $H_2$ plasmas

$V_d$ = 70 V, $I_d$ = 5 A,
$p(H_2)$ = 1.5 mTorr

Intensity of M.F. : ● 150G, ■ 120G, × 100G, ▲ 80G, ◆ 60G



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# Axial distributions of plasma parameters in $D_2$ plasmas

$V_d$ = 70 V, $I_d$ = 5 A, $p(D_2)$ = 1.5 mTorr

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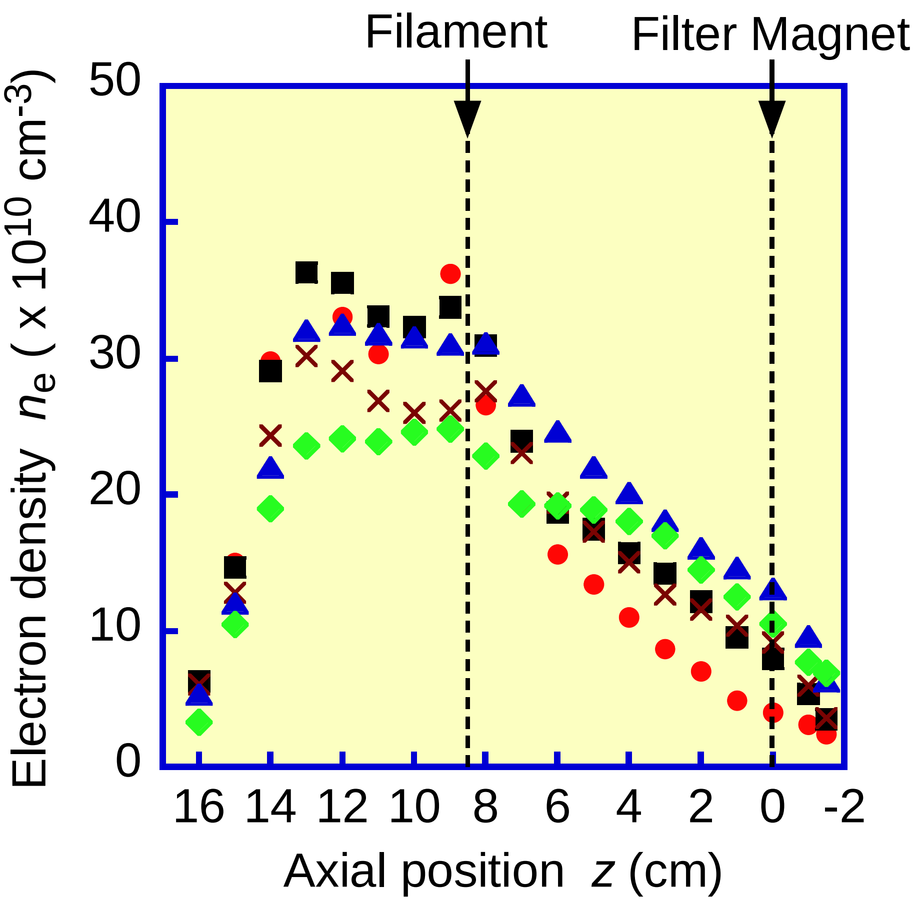
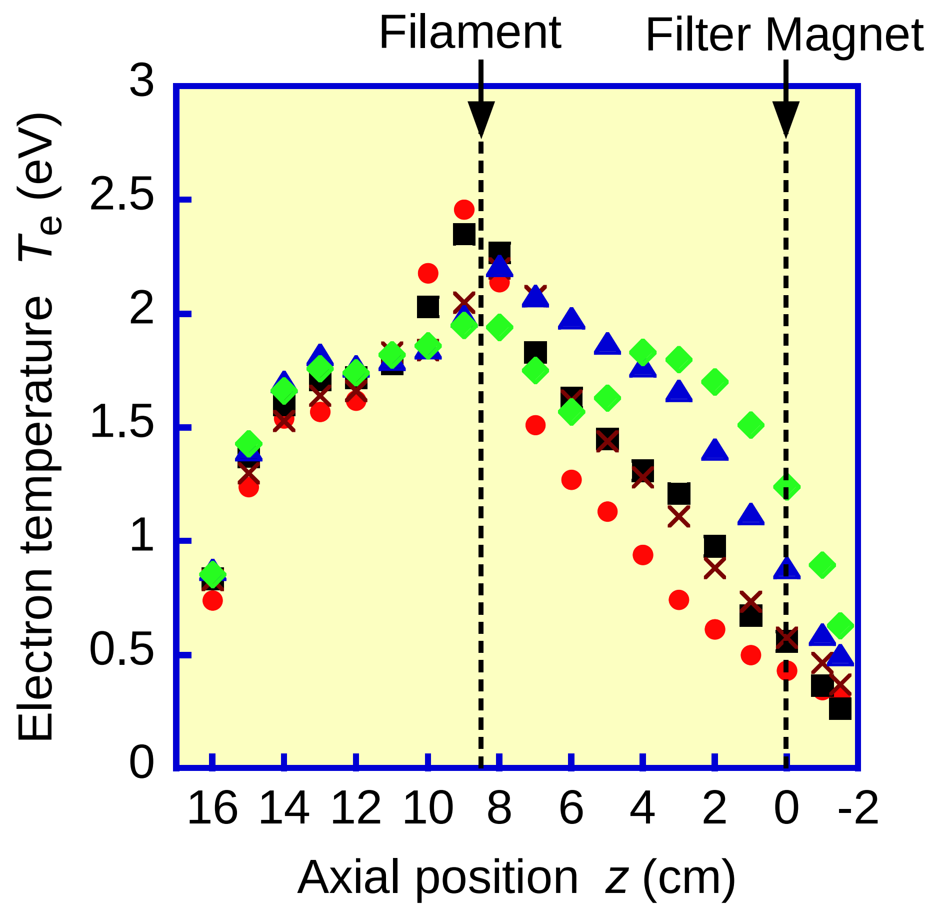
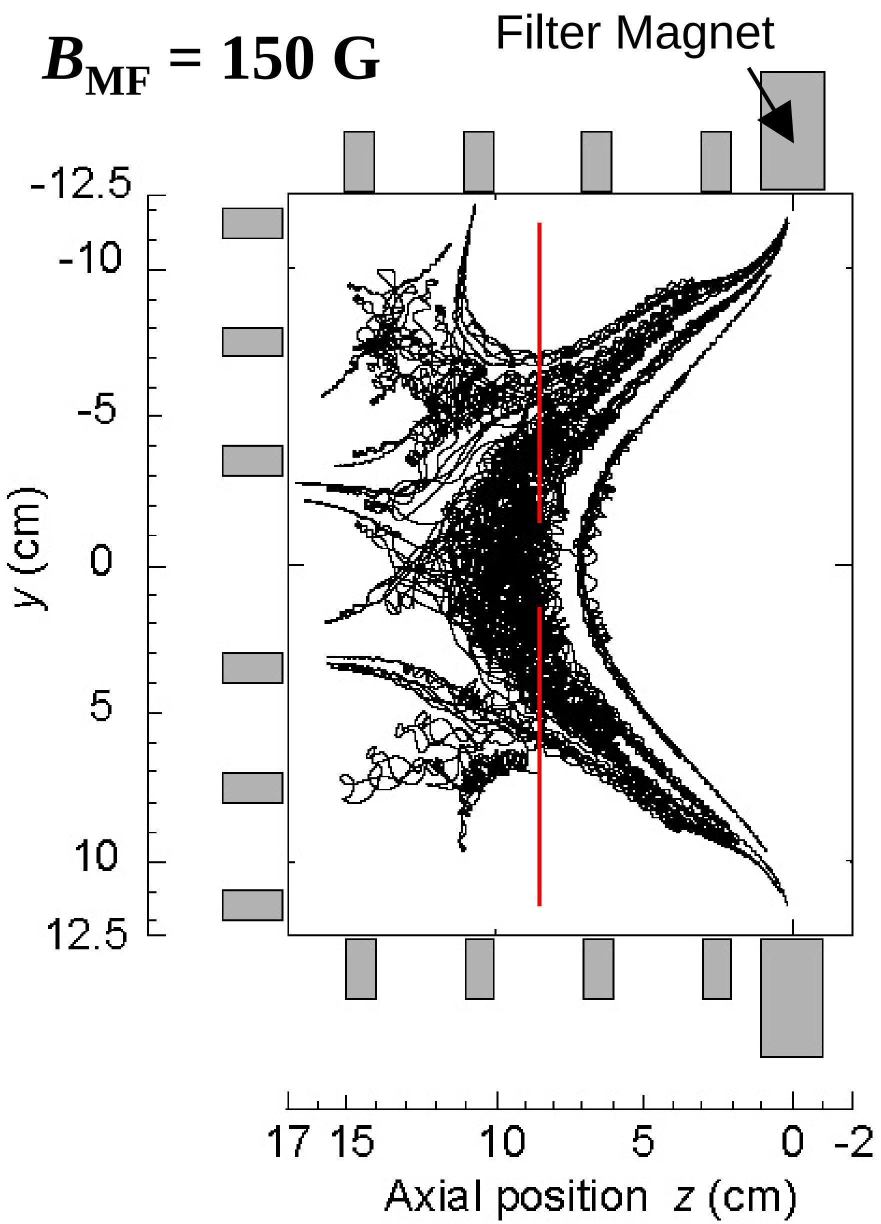
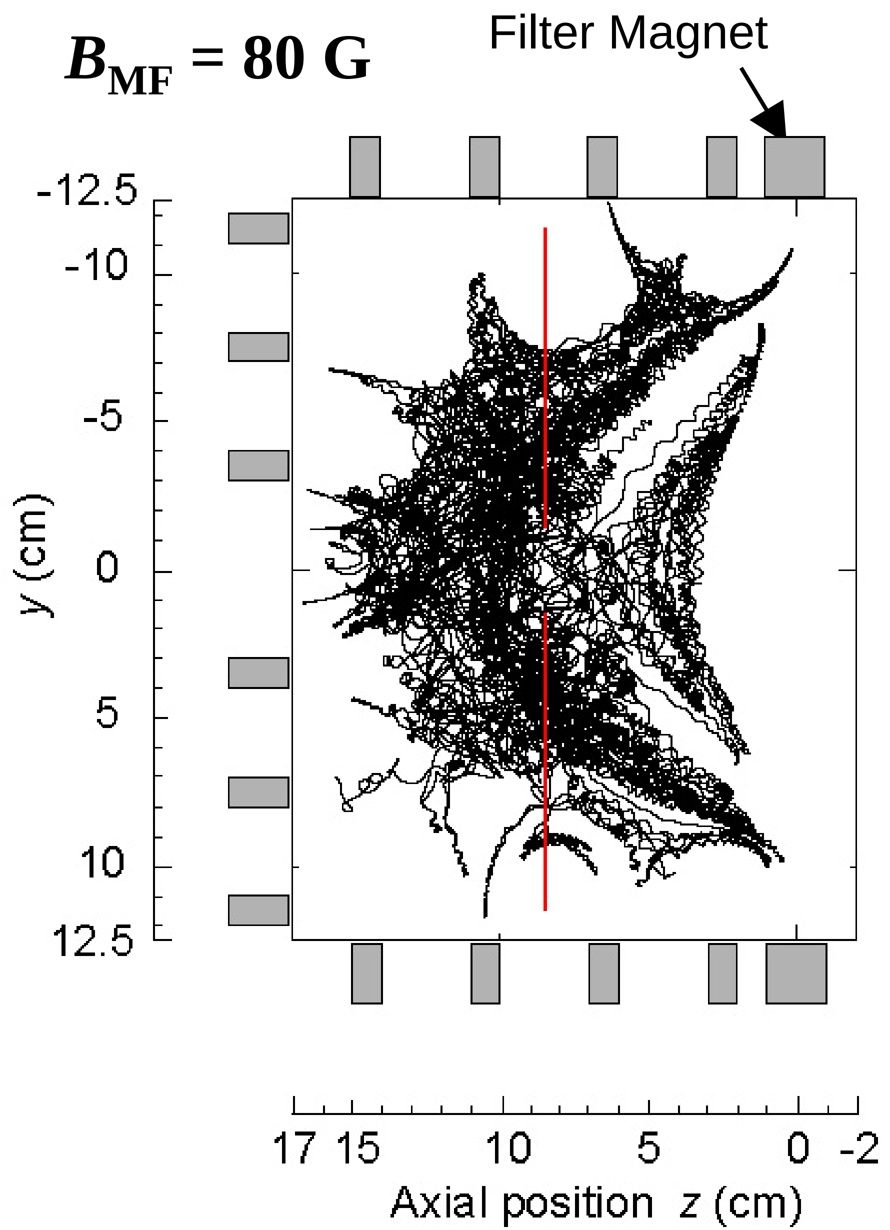


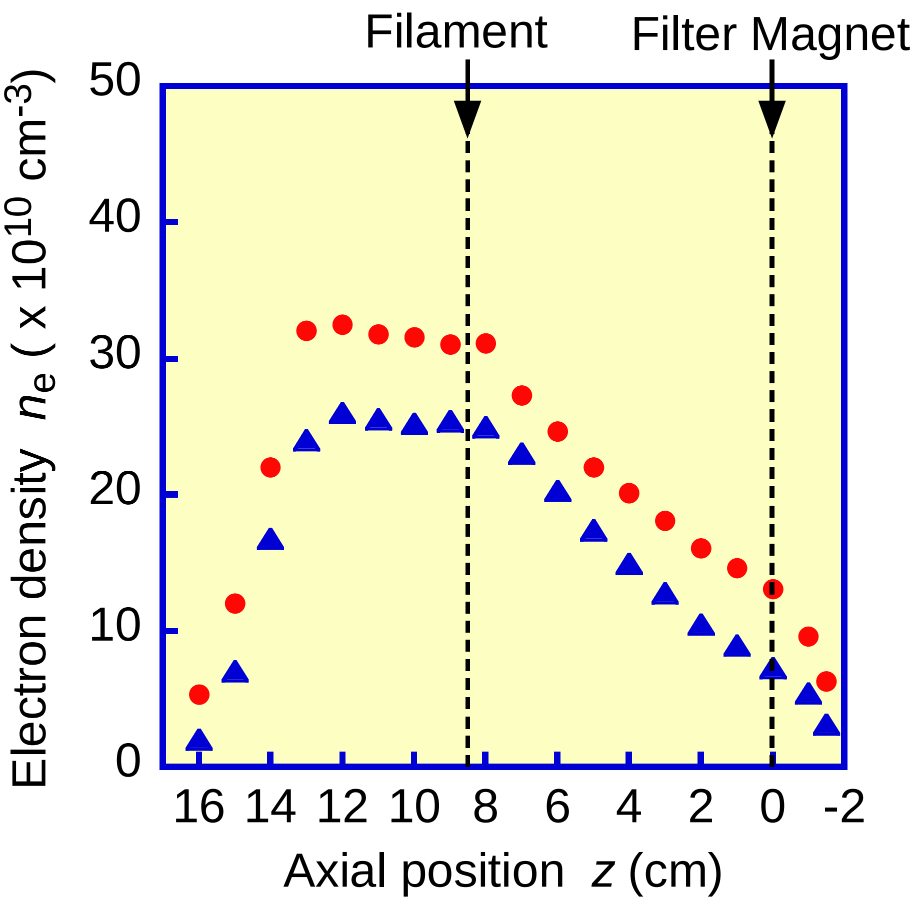
# Behaviors of primary electrons in the source

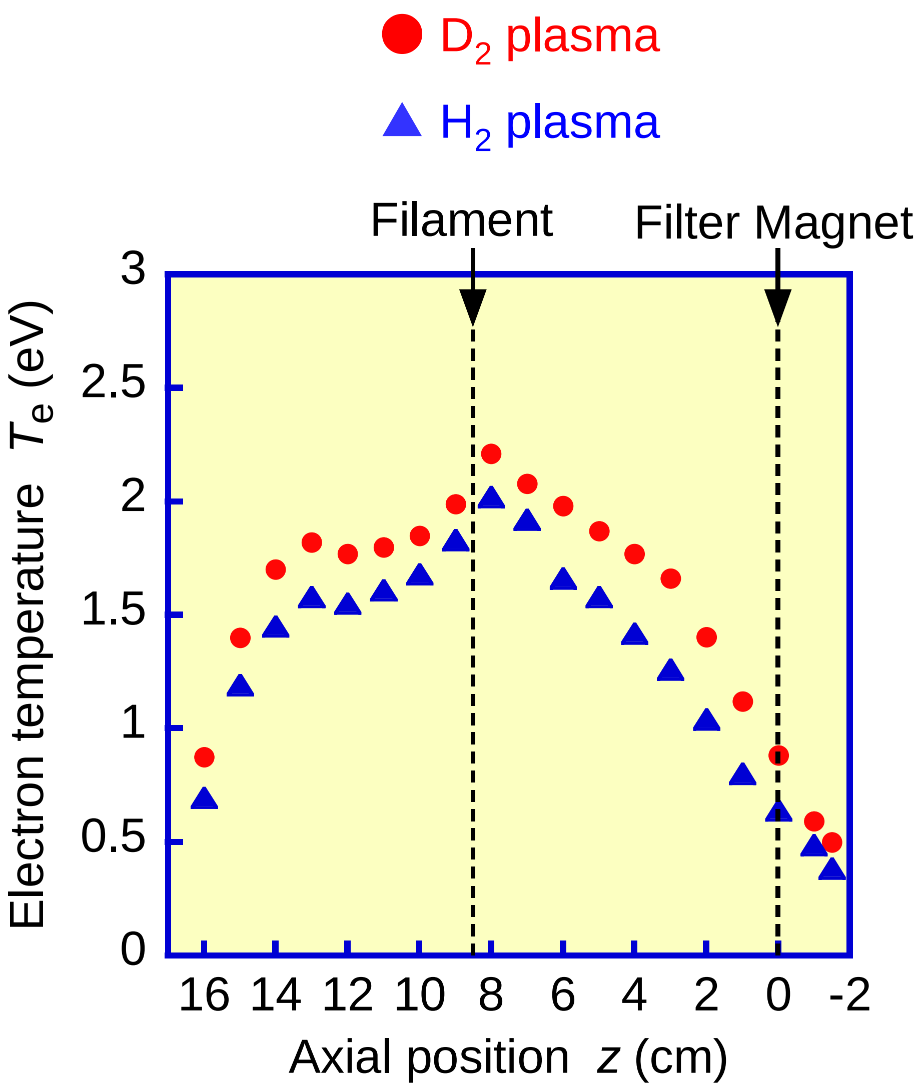


# Axial distributions of plasma parameters at $B_{MF}$ = 80 G

$B_{MF}$ = 80 G, $V_d$ = 70 V, $I_d$ = 5 A,
$p(H_2 \text{ or } D_2)$ = 1.5 mTorr



# Volume production versus plasma parameters

## *Main Process*

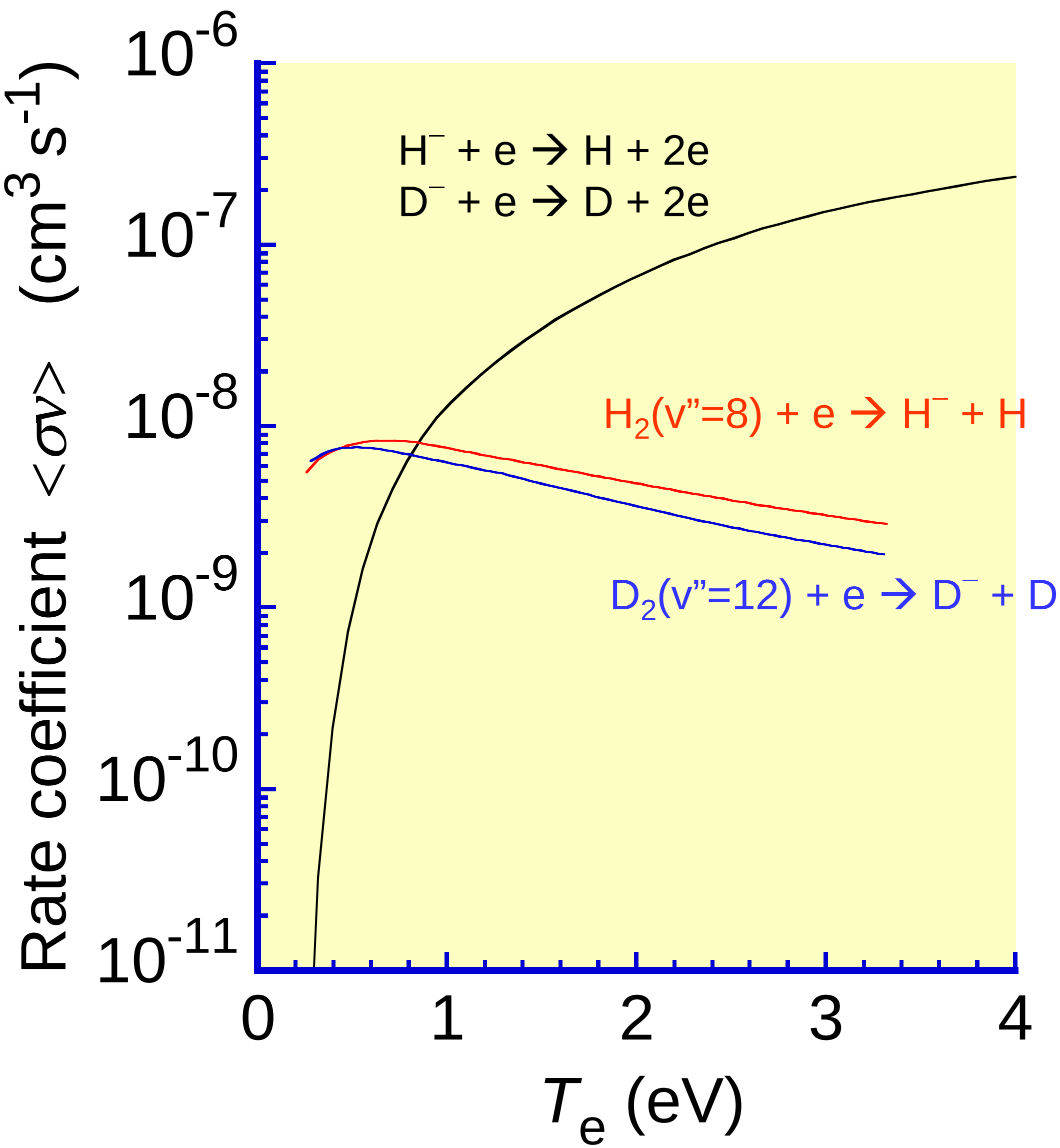
Dissociative Attachment (DA)

$D_2(v'') + e \rightarrow D^- + D$

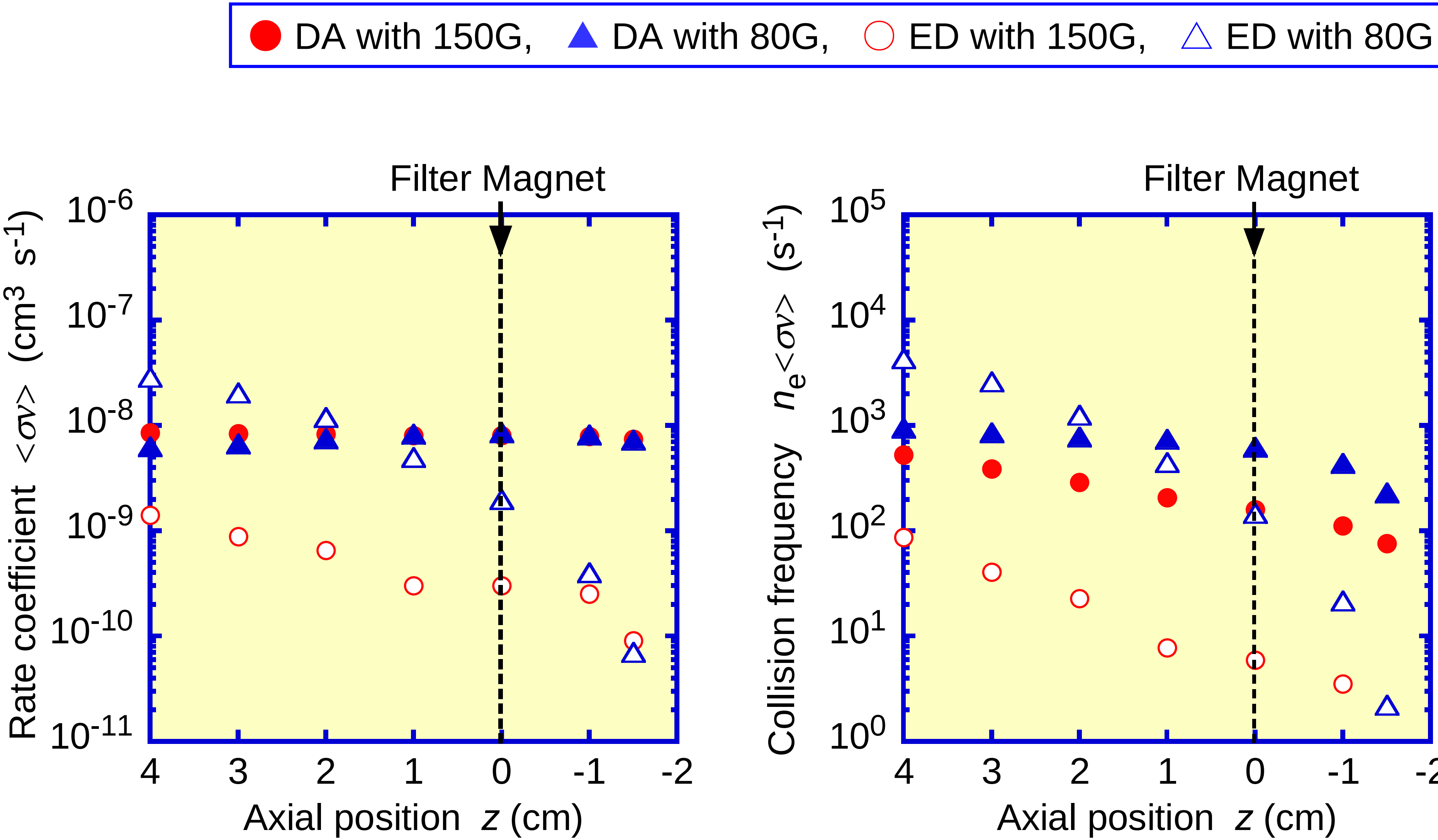
Electron Detachment (ED)

$D^- + e \rightarrow D + 2e$

$T_e$ dependence of negative ion production and destruction



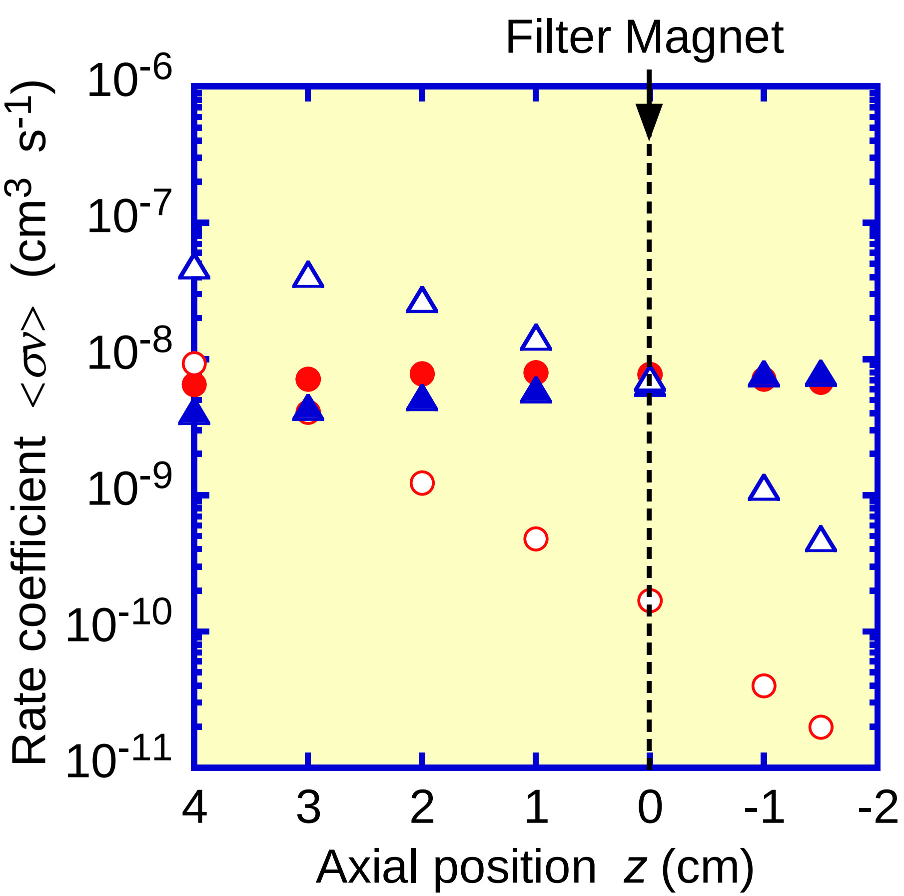
# Axial distributions of estimated $<\sigma v>$ and $n_e<\sigma v>$

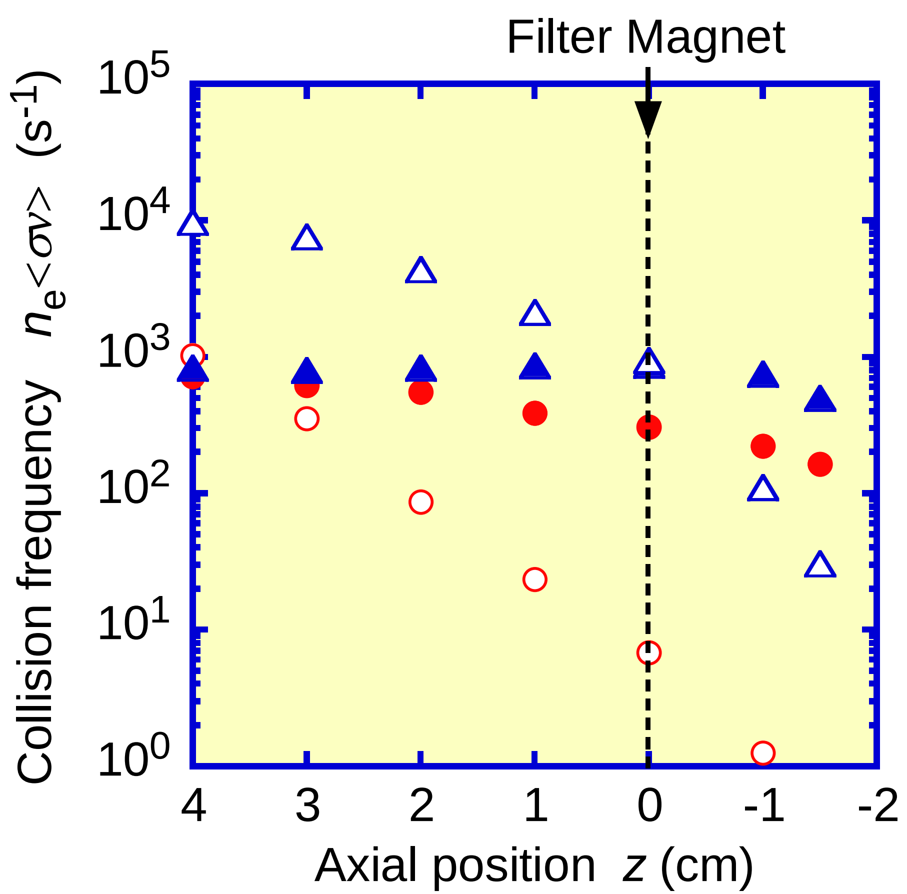



**Experimental conditions are as follows: $V_d$ = 70 V, $I_d$ = 5 A, $p(H_2)$ = 1.5 mTorr**

# Axial distributions of estimated <σv> and $n_e$<σv>

● DA with 150G, ▲ DA with 80G, ○ ED with 150G, △ ED with 80G



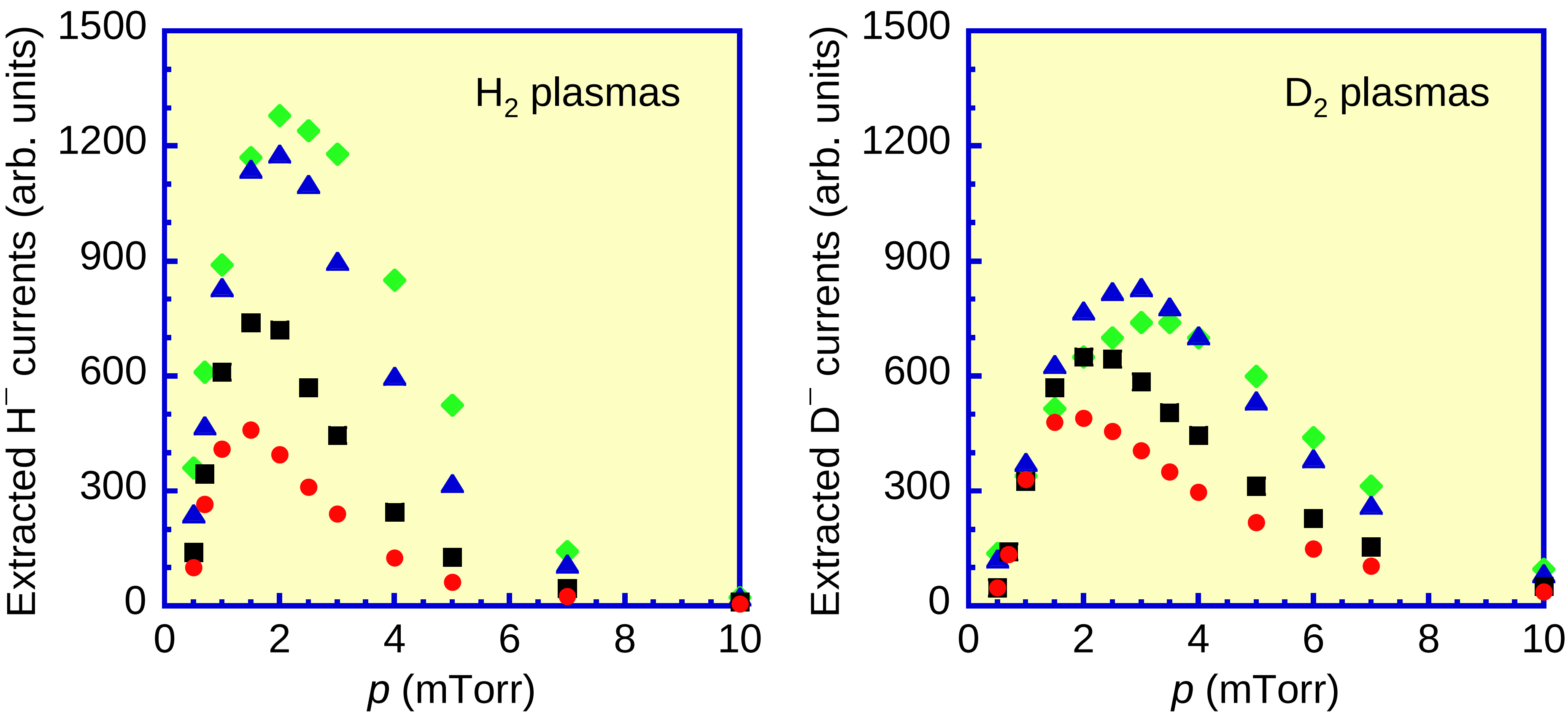




**Experimental conditions are as follows: $V_d$ = 70 V, $I_d$ = 5 A, $p(D_2)$ = 1.5 mTorr**

# Pressure dependence of extracted H$^-$ and D$^-$ currents

**$V_d$ = 70 V, $I_d$ = 5 A**
**$V_{ex}$ ~ 1.5 kV**
**Extraction position: $z$ = -2.5 cm**

Intensity of M.F. :
● 150G, ■ 120G, ▲ 80G, ◆ 60G



# Negative ion densities versus negative ion currents

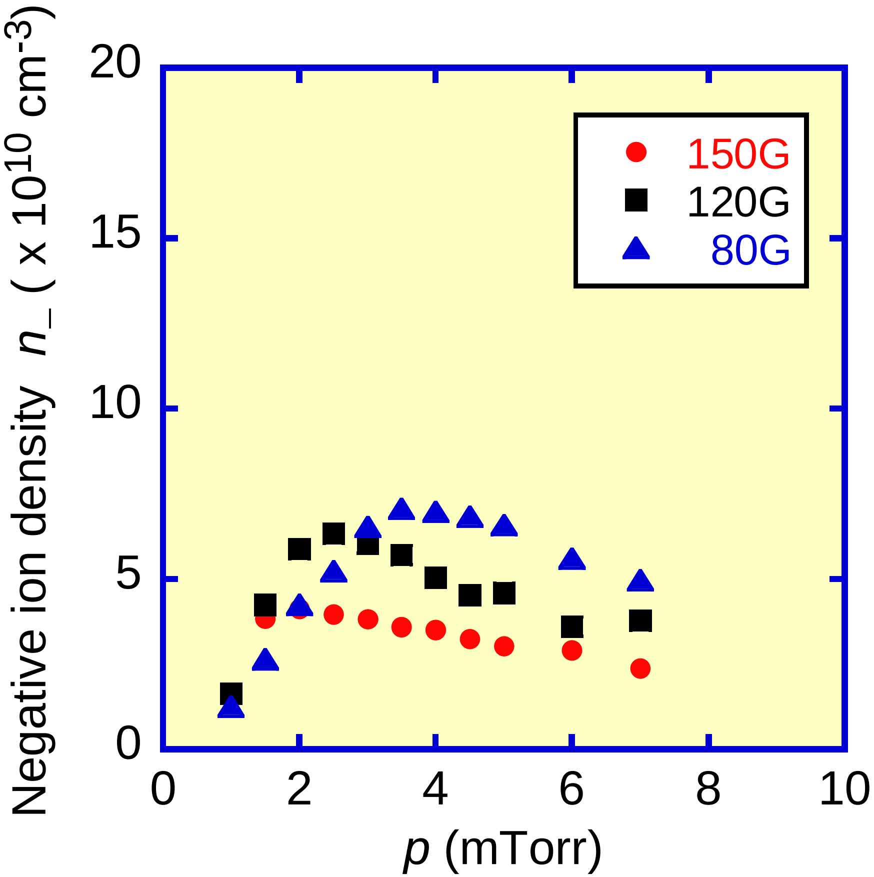
D$_2$ plasmas

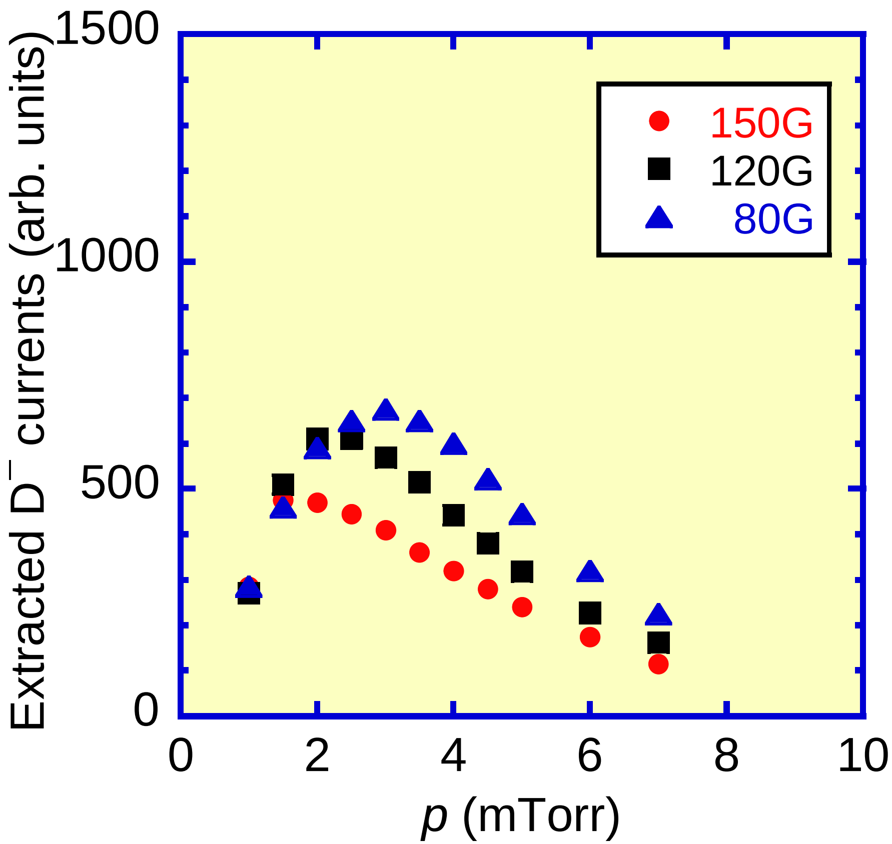
$V_d$ = 70 V, $I_d$ = 5 A
$V_{ex}$ ~ 1.5 kV

Intensity of M.F.:
●150G, ■120G, ▲80G

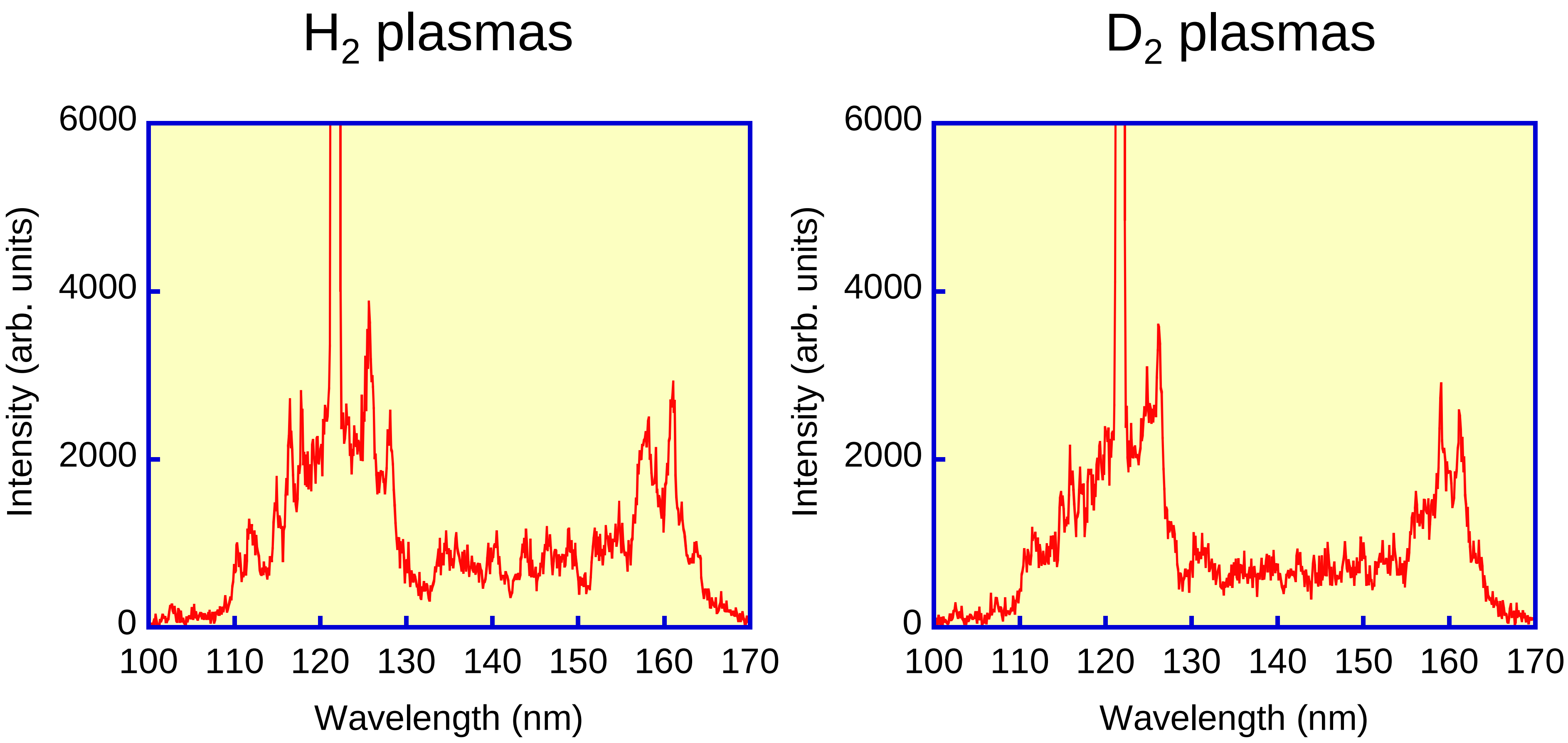
Measurement position: $z$ = -0.5 cm
（1 cm from Plasma Grid）

Extraction position: $z$ = -1.5 cm
(Plasma Grid position)



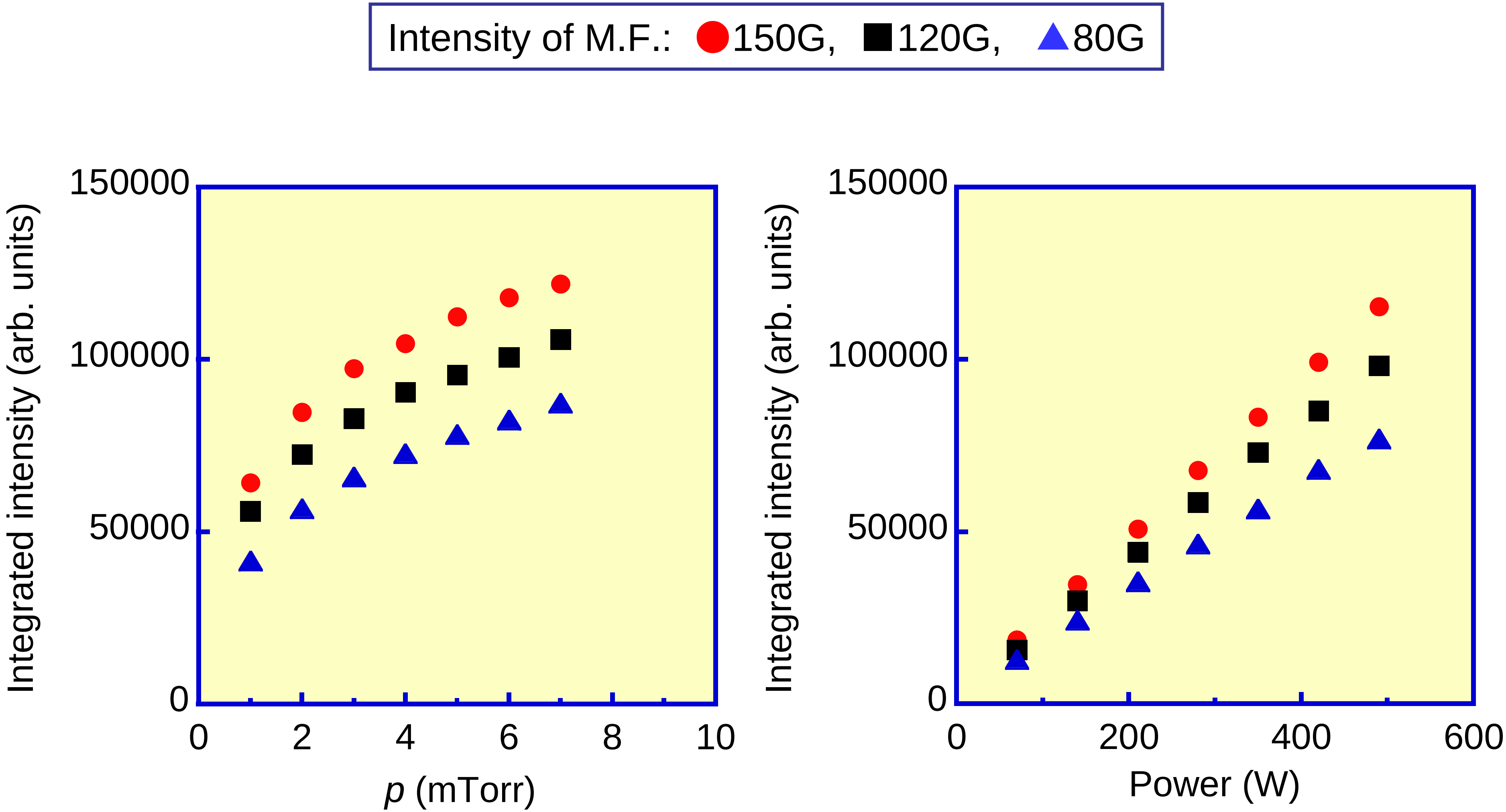



# Typical VUV spectra from $H_2$ and $D_2$ plasmas




**$B_{MF}$ = 80 G, $V_d$ = 70 V, $I_d$ = 5 A, $p$($H_2$ or $D_2$) = 3 mTorr**

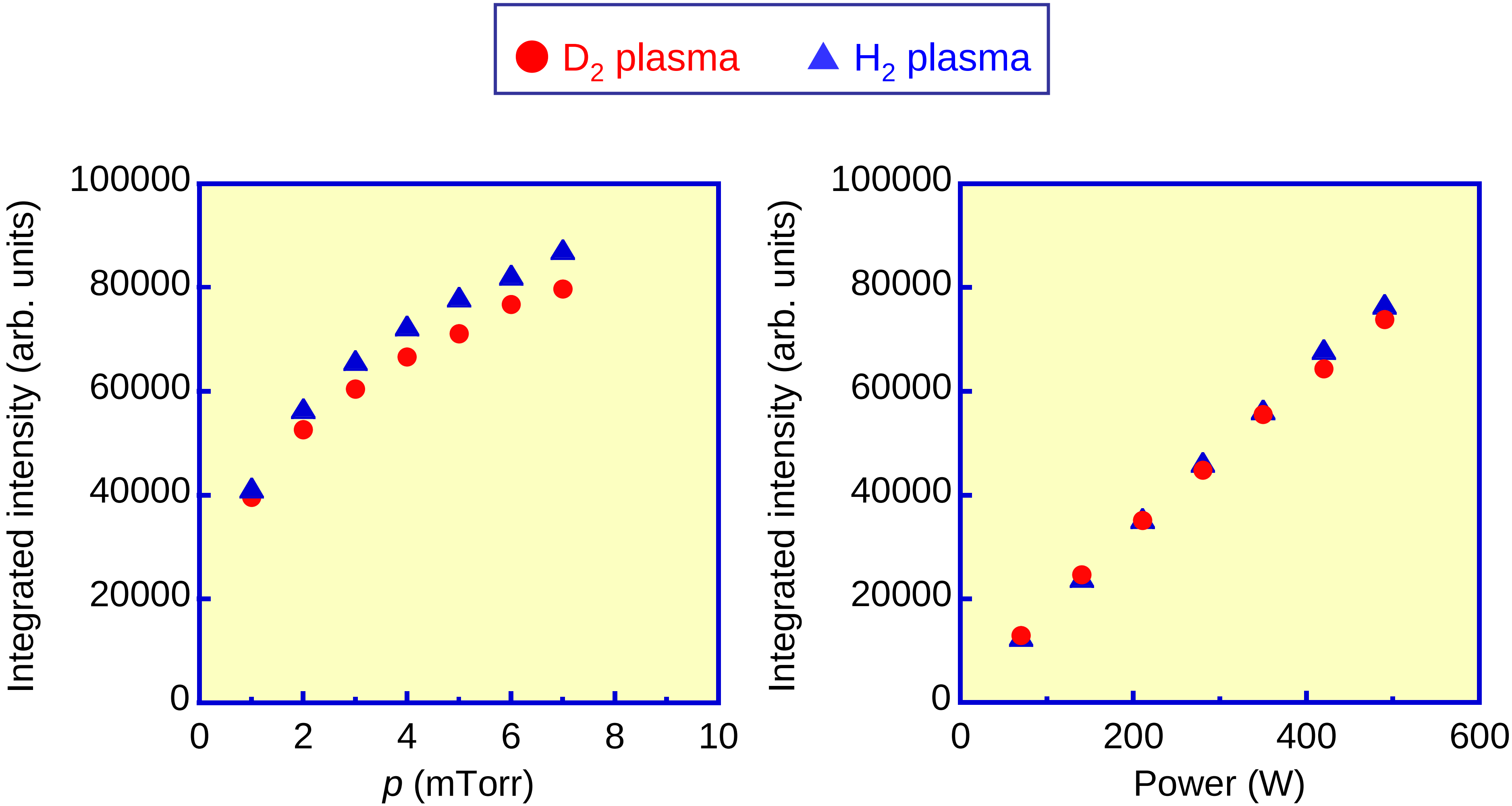
# Integrated VUV spectra from $H_2$ plasmas




$V_d$ = 70 V, $I_d$ = 5 A, $p(H_2)$ = 1 - 7 mTorr

$p(H_2)$ = 2 mTorr, $V_d$ = 70 V, $I_d$ = 1 - 7 A

# Integrated VUV spectra from $H_2$ and $D_2$ plasmas




$B_{MF}$ = 80 G, $V_d$ = 70 V, $I_d$ = 5 A

$B_{MF}$ = 80 G, $p(H_2$ or $D_2)$ = 2 mTorr

# Summary

(1) Production and control of $D_2$ plasmas

- Controlling spatial distributions of $n_e$ and $T_e$ with the MF
- Good Combination between the MF and the filament position

(2) Volume production of $D^-$ ions (Isotope effect)

- Optimum condition for $D^-$ production is different from that for $H^-$ production. (for example, pressure)
- Extracted $H^-$ and $D^-$ currents have clear relations with ion densities in the source.
- VUV emission from $D_2$ plasmas is slightly lower than that from $H_2$ plasmas. (0.9 ~ 0.95)

For further studying $D^-$ production, simultaneous measurements of VUV emission and negative ion density in the source is necessary.

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# END

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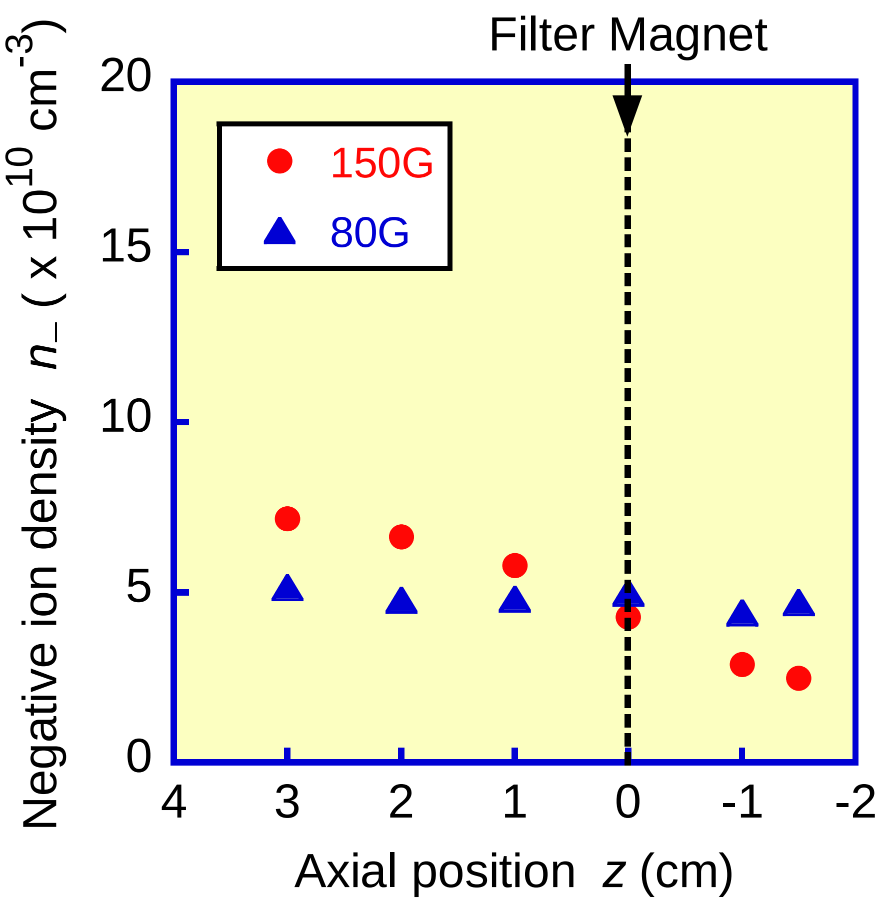
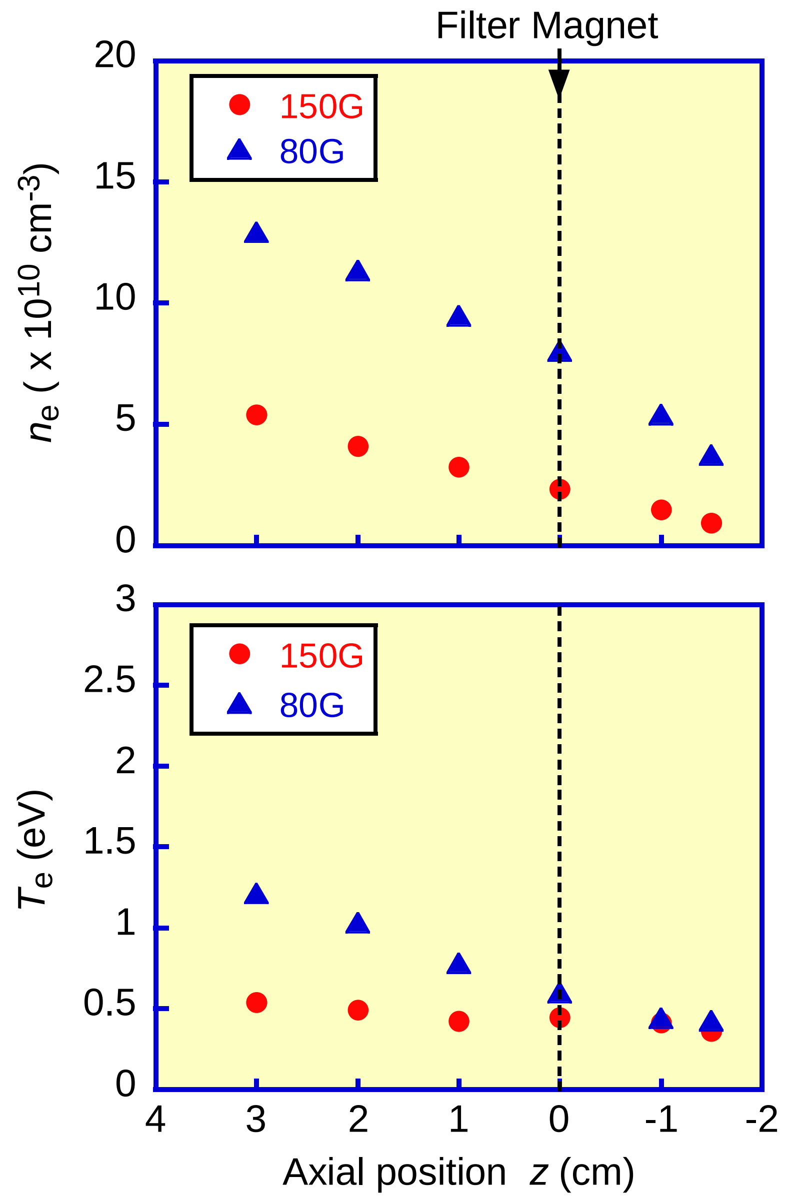
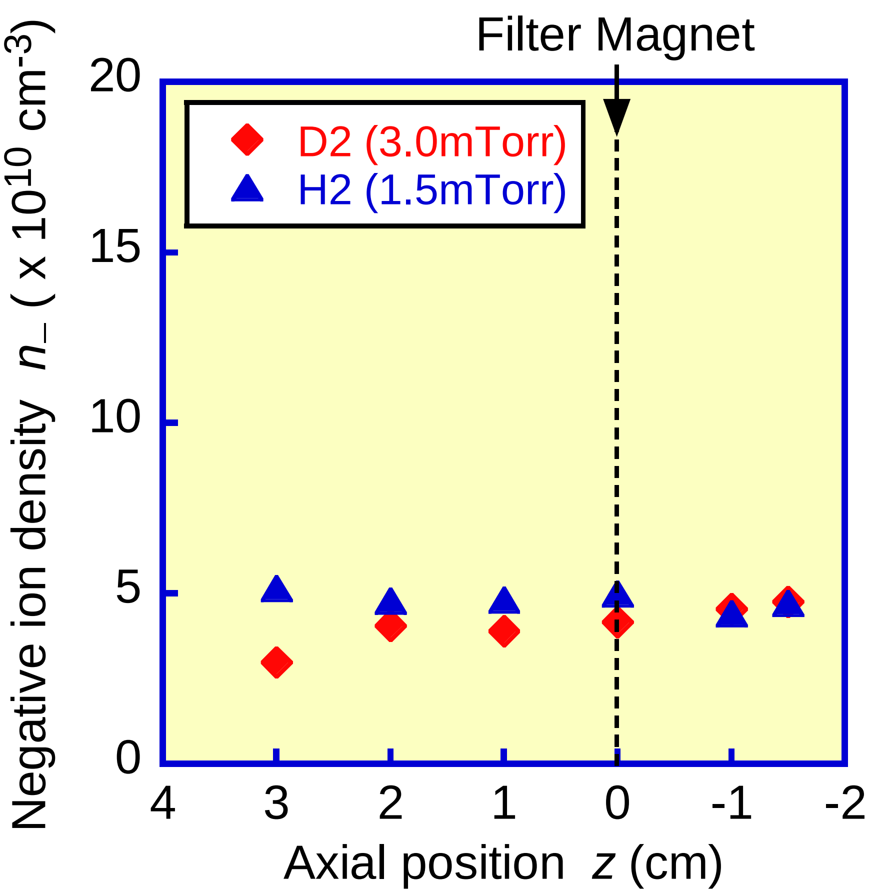
# Axial distributions of $H^-$ ion densities

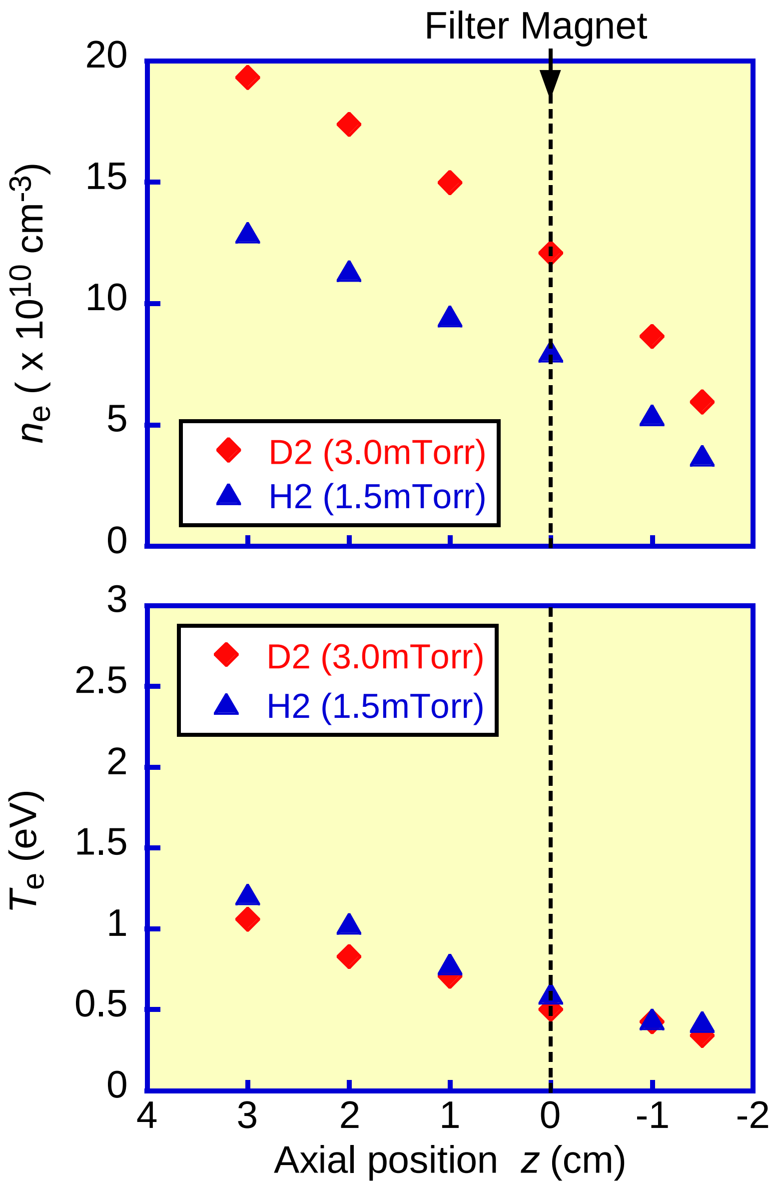



**$V_d$ = 70 V, $I_d$ = 5 A, $p(H_2)$ = 1.5 mTorr,**
**$E_{laser}$ = 30 mJ, $D_{laser}$ = 6 mm, $V_p$ = 10 V.**

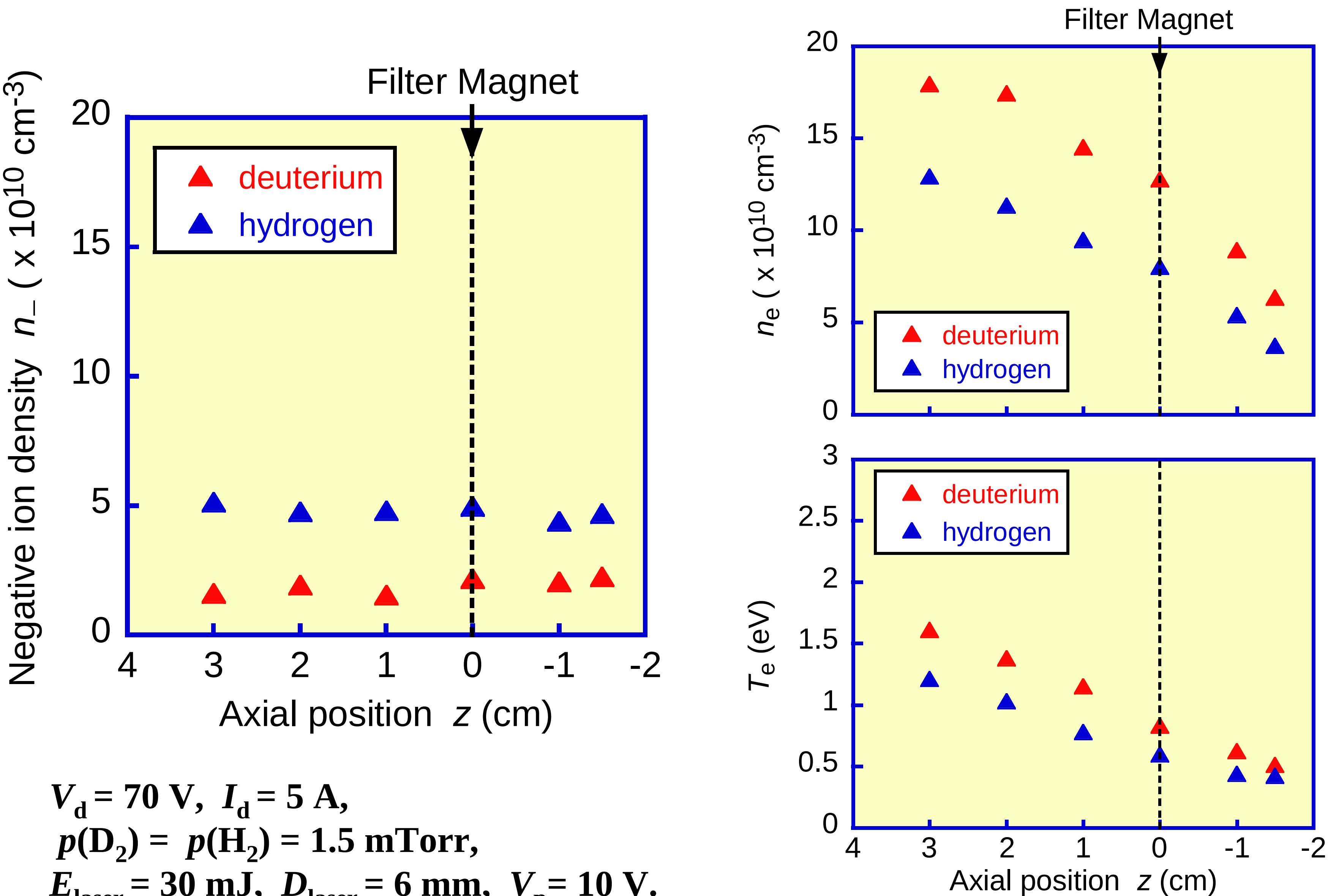
# Axial distributions of H⁻ and D⁻ ion densities




$V_d = 70$ V, $I_d = 5$ A,
$p(D_2) = 3$ mTorr, $p(H_2) = 1.5$ mTorr,
$E_{laser} = 30$ mJ, $D_{laser} = 6$ mm, $V_p = 10$ V.

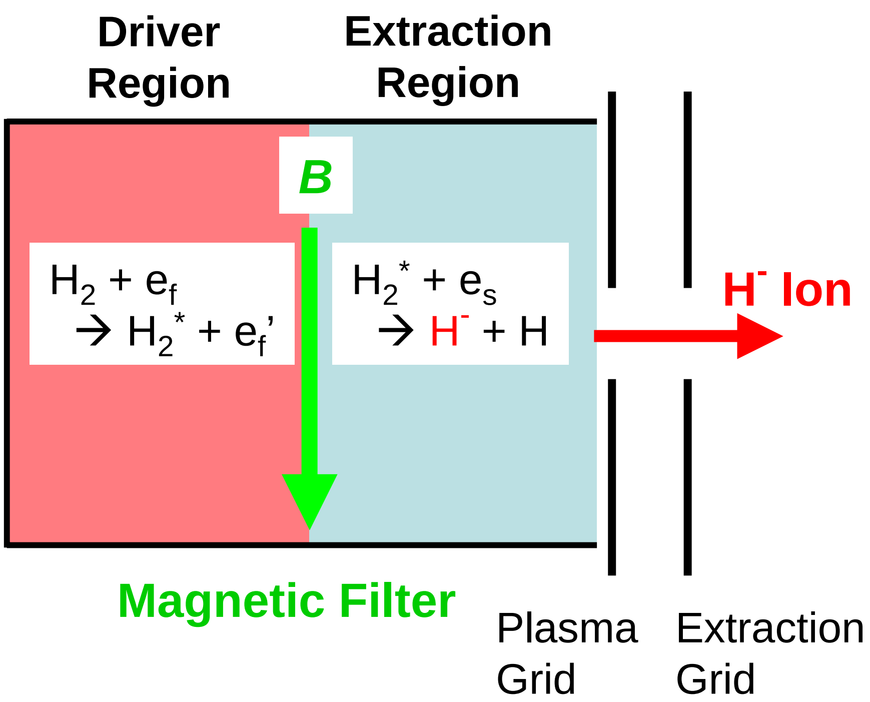
# Axial distributions of $H^-$ and $D^-$ ion densities



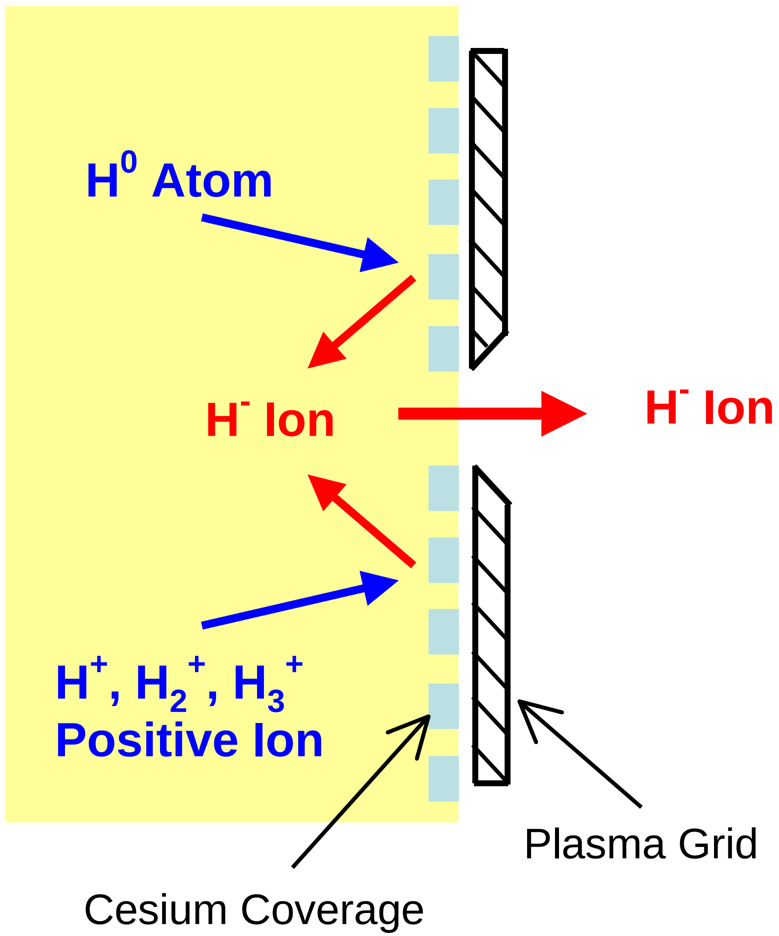

**$V_d$ = 70 V, $I_d$ = 5 A,**
**$p(D_2)$ = $p(H_2)$ = 1.5 mTorr,**
**$E_{laser}$ = 30 mJ, $D_{laser}$ = 6 mm, $V_p$ = 10 V.**

# Production Processes of Negative Ions

## Volume Production




## Surface Production Process in Cs-seeded Volume Negative Ion Source

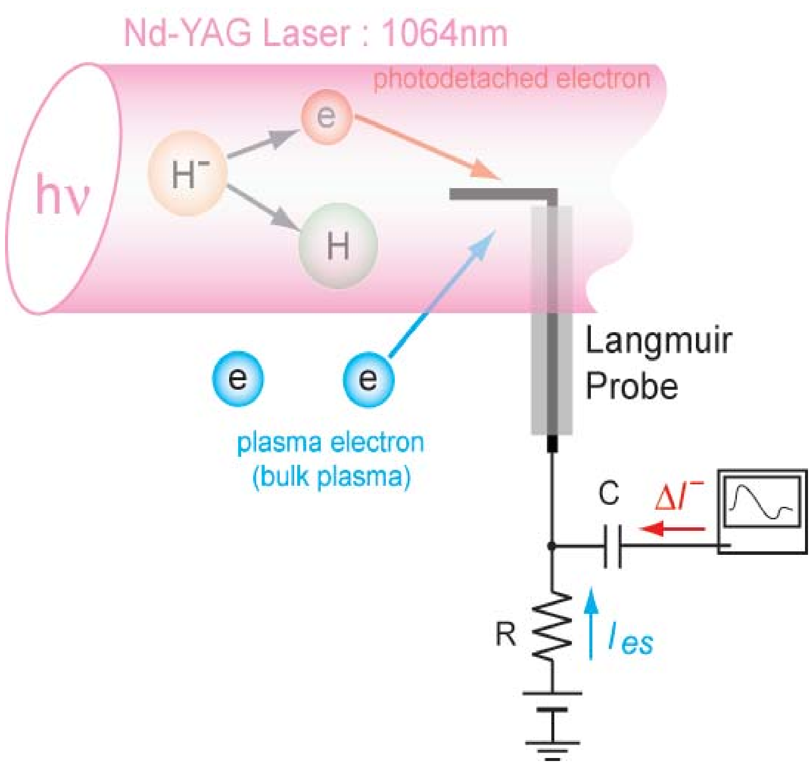


# Negative ion density measurement by laser photodetachment

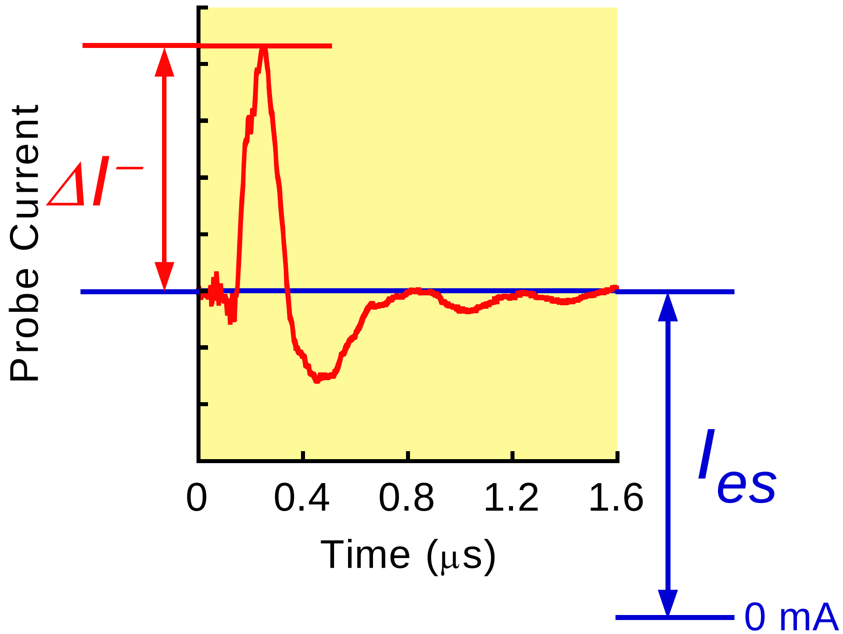
Photodetachment process

$$H^{-} + h\nu \rightarrow H + e$$

Laser beam




**Photodetached signals**



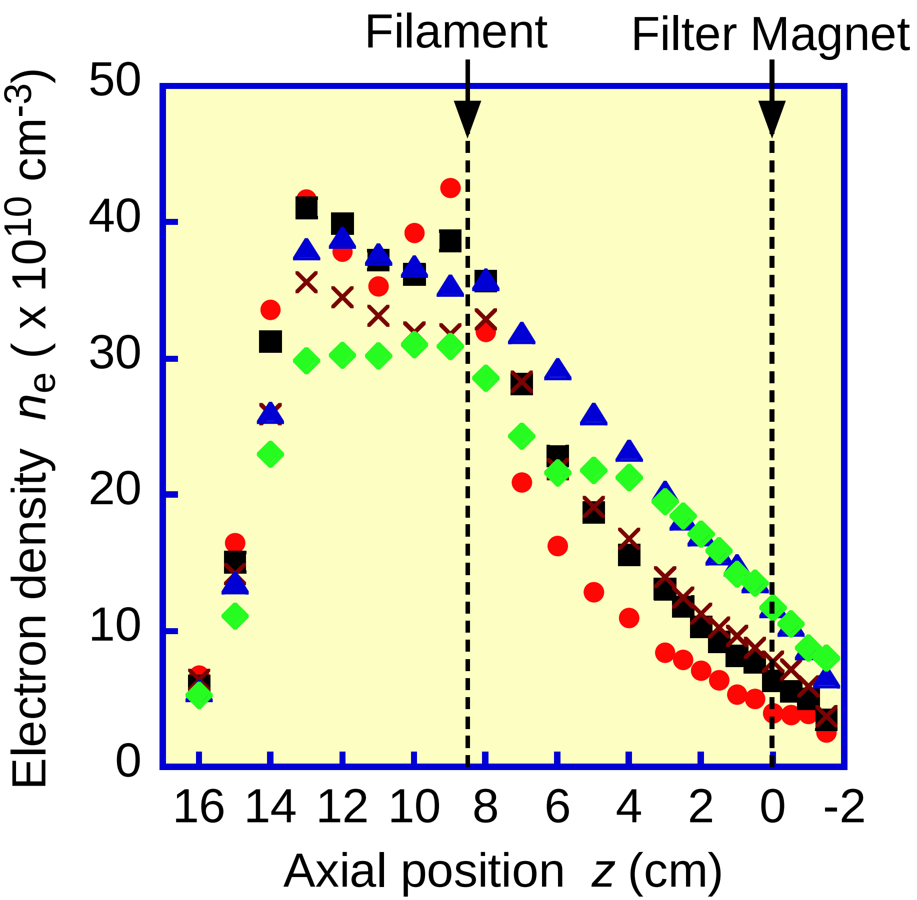

**Negative ion density $n_-$**

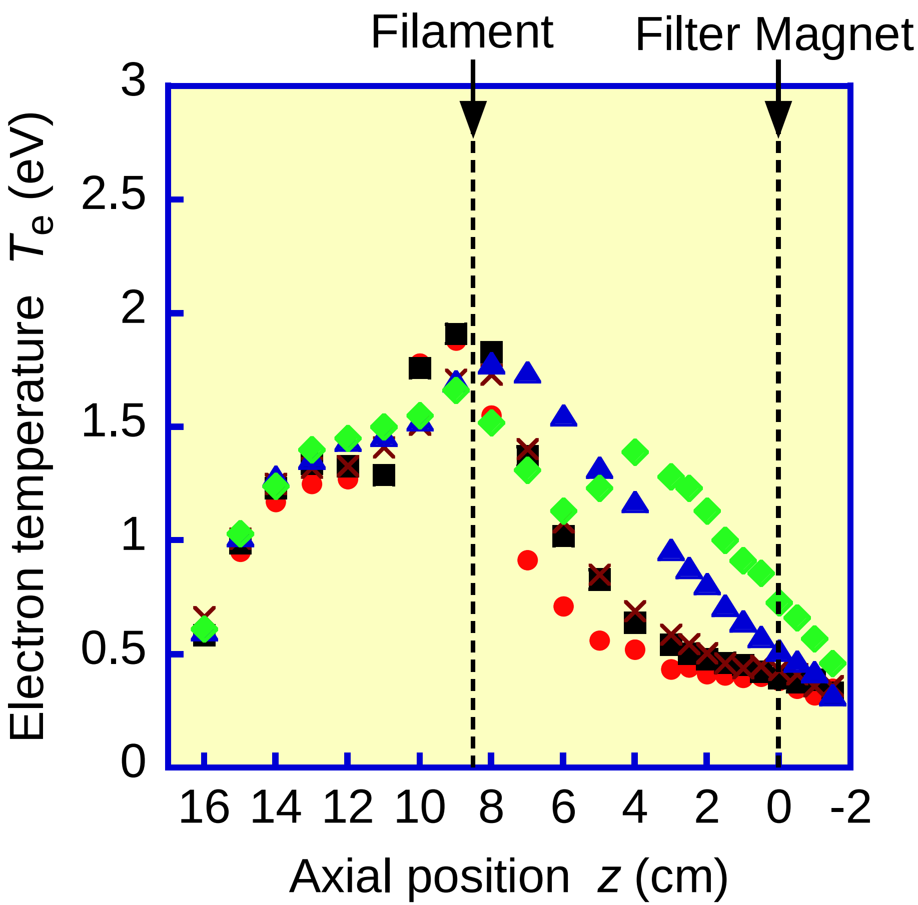
$$\frac{n_-}{n_e} = \frac{\Delta I^-}{I_{es}}$$

# Axial distributions of plasma parameters in $D_2$ plasmas

$V_d = 70$ V, $I_d = 5$ A,
$p(D_2) = 3$ mTorr

Intensity of M.F. : ●150G, ■120G, ×100G, ▲80G, ◆60G



# Axial distributions of estimated <σv> and $n_e$<σv>

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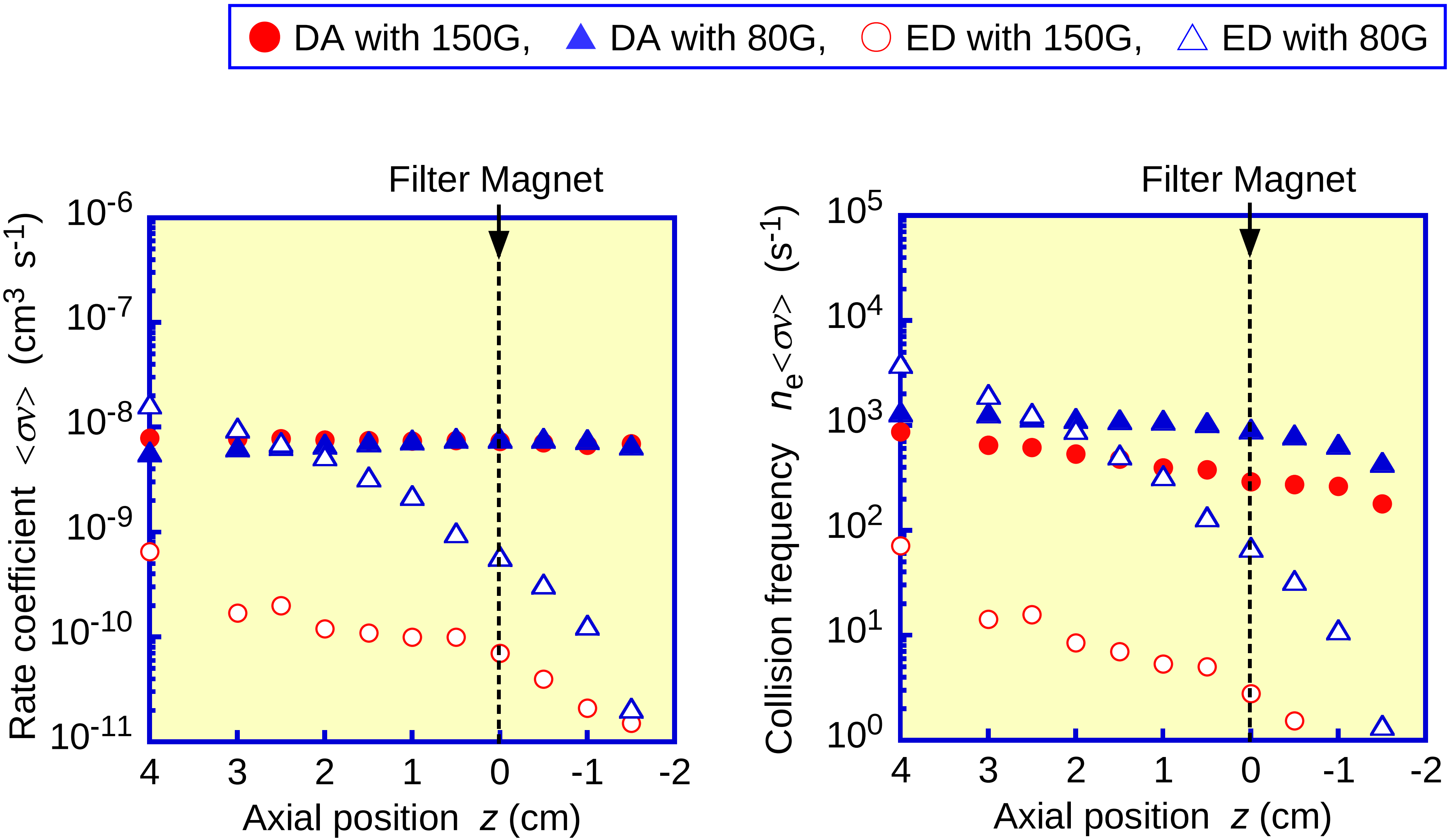
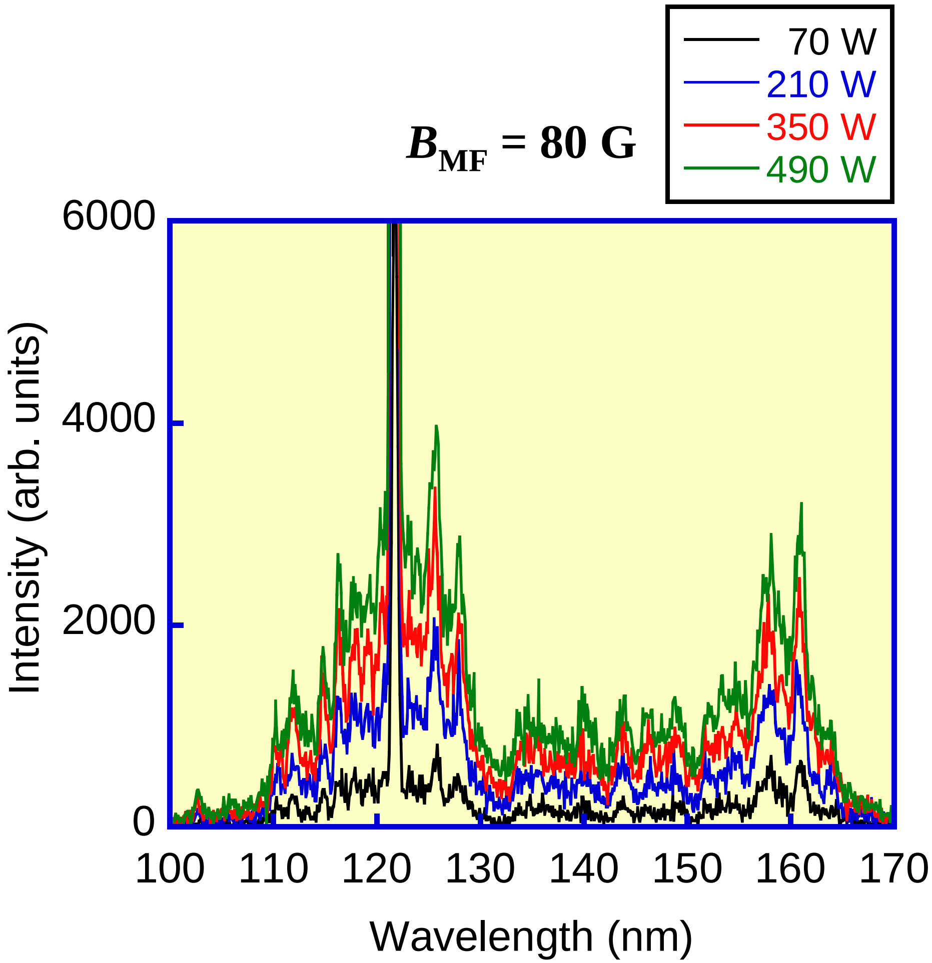
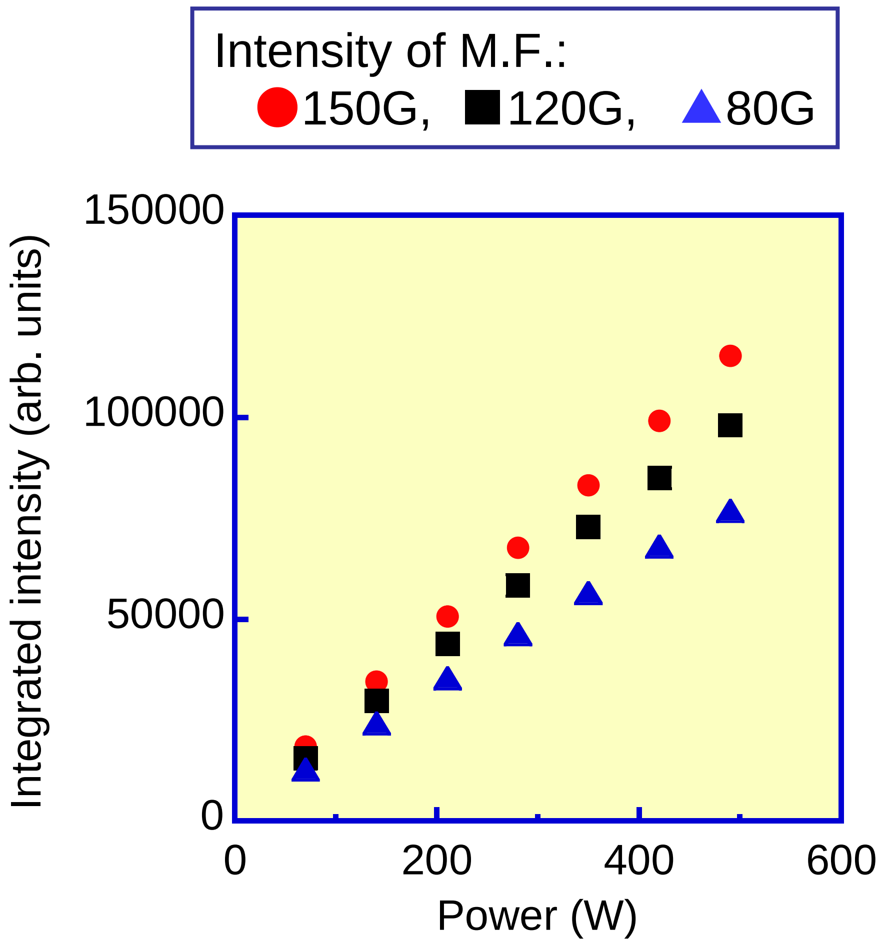



**Experimental conditions are as follows: $V_d$ = 70 V, $I_d$ = 5 A, $p(D_2)$ = 3.0 mTorr**

# Power dependence of VUV spectra from $H_2$ plasmas


**$p(H_2)$ = 2 mTorr, $V_d$ = 70 V, $I_d$ = 1 - 7 A**